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(71) Applicant: FUJITSU TEN LIMITED
1-2-28 Gosho-dori, Hyogo-ku
Kobe-shi, Hyogo (JP)

(72) Inventor: Ichimura, Atsushi
2-32-23, Higashiohike, Kita-ku
Kobe-shi, Hyogo (JP)
Inventor: Nakatani, Yasuhiro
2-26-902, Hanayamahigashi, Kita-ku
Kobe-shi, Hyogo (JP)

(74) Representative: Skone James, Robert Edmund
GILL JENNINGS & EVERY 53-64 Chancery Lane
London WC2A 1HN (GB)

(54) Direction sensor having an earth magnetism sensor and a rate gyro sensor and navigation system having this direction sensor.

(57) Disclosed is a direction sensor and a navigation system containing said direction sensor. The direction sensor has an earth magnetism sensor (1) and a rate gyro sensor (2) that calculates a compensated direction by weighted means process of outputs from the earth magnetism sensor and the rate gyro sensor. The compensated direction has a high detection accuracy similar to the rate gyro sensor in a short time, but does not have an error accumulation of the rate gyro sensor in a long time because the rate gyro sensor is substantially calibrated with the accurate direction obtained by averaging outputs of the earth magnetism sensor. The navigation system has distribution information of the magnetic disturbances to earth magnetism on a map (5) and it reduces the weighted mean ratio to the earth magnetism sensor (1) when the magnetic disturbance at locating position is large. The accuracy of the compensated direction is further improved by excluding inaccurate outputs of the earth magnetism sensor (1).

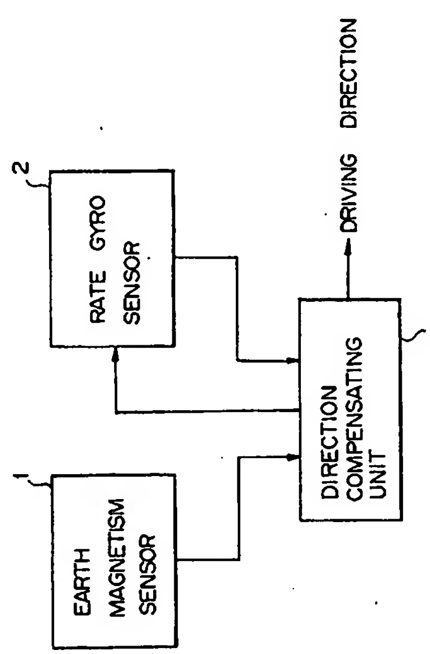

Fig. 1

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Jouve, 18, rue Saint-Denis, 75001 PARIS

The present invention relates to a direction sensor having an earth magnetism sensor and a rate gyro sensor, and a navigation system of a vehicle having this direction sensor for locating a position on a map. More particularly, this invention relates to an improvement of detection accuracy of a driving direction sensor and navigation system.

Vehicles are recently equipped with a navigation system that detects driving paths and displays position on a map and offers instructions to aid a driver. The navigation system includes a driving direction sensor and a driving distance sensor, and calculates a position on a map from the driving direction and the driving distance. The direction sensor used in the above system is required to detect the absolute direction corresponding to the direction on a map.

Two types of direction sensors are generally used in the navigation system. One type is a rate gyro sensor that detects a rotation speed and calculates a rotated angle from a reference direction. A conventional gyro having a gimbal, an optical fiber gyro and a gas rate sensor are included in this rate gyro sensor. The rate gyro sensor generally has characteristics such that the detection accuracy is very high in a short time range, but it deteriorates in a long time range due to the accumulation of errors. Therefore, the rate gyro sensor needs to be periodically calibrated. This calibration is performed by the absolute direction. Further, the rate gyro sensor needs to be initialized to set the reference direction at the start of the operation because it calculates the rotated angle from the reference direction. This initialization is also performed by the absolute direction and the calibration is substantially equal to the initialization.

The other type is an earth magnetism sensor that detects a forward angle of a vehicle relative to magnetic north of earth and calculates an absolute direction on a map. The earth magnetism sensor has an advantage in that it can detect an absolute direction and detecting errors do not accumulate. However, because the intensity of earth magnetism is as low as 0.3 Gauss, the detection of earth magnetism is disturbed by various external magnetic factors such as polarization of a vehicle body, and a magnetic field due to electrical equipment of a vehicle. Further, various facilities such iron bridges, large buildings, high level roads and tunnels also disturb the earth magnetism. These disturbances cause errors in the detection of the earth magnetism sensor. Various methods are proposed for compensating for the disturbance due to a polarization of a vehicle body, and it can be reduced by using such a method. However, the disturbances due to facilities cannot be compensated because these disturbances exist at random.

As the rate gyro sensor and the earth magnetism sensor respectively have the above-mentioned characteristics, a conventional navigation system generally comprises both a rate gyro sensor and an earth magnetic sensor and calculates a precise driving direction by compensating each other's results. For example, in a navigation system disclosed in Japanese Unexamined Utility Model Publication (Kokai) No. 62-163721, the errors of an earth magnetism sensor due to the polarization of a vehicle is compensated for by the difference of the outputs of the earth magnetism sensor and the rate gyro sensor.

In the most orthodox system, the rate gyro sensor is normally used as a driving direction sensor, and the output of the earth magnetism sensor is used only as a reference direction of the initialization and the periodical calibrations of the rate gyro sensor. This system has problems in that the reference direction obtained from the earth magnetism sensor is not necessarily precise and the accumulation of errors of the rate gyro sensor is not reduced.

In a navigation system disclosed in Japanese Unexamined Utility Model Publication (Kokai) No. 62-163721, the errors of an earth magnetism sensor due to the polarization of a vehicle is compensated for by the difference of the outputs of the earth magnetism sensor and the rate gyro sensor.

In a navigation system disclosed in Japanese Unexamined Utility Model Publication (Kokai) No. 61-72618, the earth magnetism sensor is normally used as a driving direction sensor and the rate gyro sensor is used when the magnetic field of the location position seems to be disturbed more than a predetermined level. The intensity of the disturbance is determined according to the difference between the outputs of the earth magnetism sensor and the rate gyro sensor in a short time range. However, if the magnetic field of earth magnetism is uniformly disturbed in a wide range, for example, when driving along a railroad or a transmission line, the incorrect output of the earth magnetism sensor is always used because the difference in the short time range is always small under this condition.

In another navigation system disclosed in Japanese Unexamined Patent Publication (Kokai) No. 64-353314, Information relating to specific facilities that largely influence the earth magnetic field and those influence patterns is disclosed. The earth magnetism sensor detects these changes of the magnetic field due to the specific facilities. The navigation system determines positions of the specific facilities and compensates the locating position according to the positions of the specific facilities. This system normally uses the rate gyro sensor as the driving direction sensor and initializes the rate gyro sensor by the above detected positions. However, the influence pattern of the facility to the magnetic field is very complex. Therefore, it is not easy to determine the facility position according to the detected changes of the magnetic field. Further, when there is no

specific facility in a wide range, the driving direction is determined only by the rate gyro sensor. Therefore, this system also has a disadvantage in that the error accumulation of the rate gyro sensor increases.

An object of the present invention is to improve the detection accuracy of the driving direction of a navigation system having an earth magnetism sensor and a rate gyro sensor and calculating the compensated driving direction from both outputs, especially, to propose a better compensation method of outputs of an earth magnetism sensor and a rate gyro sensor.

According to one aspect of the present invention, the navigation system includes an earth magnetism sensor, a rate gyro sensor and a driving direction compensating means which calculates the compensated driving direction by a weighted mean of outputs of the earth magnetism sensor and the rate gyro sensor, and the compensated driving direction is set as a reference direction of the rate gyro sensor.

As described in the above, the rate gyro sensor has a very high accuracy in a short time range. On the other hand, the detection accuracy of the earth magnetism sensor is disturbed by external factors due to facilities and topographical conditions. However, the average value of outputs of the earth magnetism sensor in a long time range is disposed to converge to a correct value. Therefore, the compensated driving direction obtained by the weighted mean process with a heavy ratio to the rate gyro sensor has an accuracy similar to the rate gyro sensor in a short time range. And, by repeating the setting process of the obtained compensated driving direction to the reference direction of the rate gyro sensor and above sampling process by turns, the detection errors of the earth magnetism sensor are averaged and the rate gyro sensor is calibrated by the precise direction. Consequently, the direction sensor has a high level accuracy corresponding to the rate gyro sensor in a short time range and it has no accumulation of errors in a long time range.

According to the another aspect of the present invention, the navigation system includes an above direction sensor, and further includes a driving distance sensor, a road map storing means for storing information relating to a road map, a locating position calculating means for calculating a locating position on a road map, a disturbance data storing means for storing distribution information of magnetic disturbance to earth magnetism in a form corresponding to the road map, and a ratio changing means for detecting an intensity of magnetic disturbance at the locating position and changing the ratio of the weighted mean process according to the magnetic disturbance intensity.

The distribution of the magnetic disturbance due to facilities and topographical factors is stable over a long time range. Therefore, if the navigation system reduces a contribution ratio of the output of the earth magnetism sensor in the high disturbance range, the accuracy of the obtained driving direction is improved.

The present invention will be more clearly understood from the description as set forth below with reference to the accompanying drawings, wherein:

Fig. 1 shows a fundamental construction of a direction sensor of the invention;

Fig. 2 shows a construction of a direction sensor of an embodiment;

Fig. 3 shows a construction of a flux gate sensor used as the direction sensor;

Figs. 4A and 4B show a flow-chart of an operation of a microcomputer shown in Fig. 2;

Fig. 5 shows an example of a function of a weighted mean ratio which changes according to a driving time of a vehicle;

Fig. 6 shows an another example of a function of a weighted mean ratio which changes according to a temperature;

Fig. 7 shows a fundamental construction of a navigation system of the invention;

Fig. 8 shows a construction of a navigation system;

Fig. 9 shows an example of magnetic disturbance data;

Fig. 10 shows an example of formats of a magnetic disturbance data;

Figs. 11A and 11B show a flow-chart of an operation of a microcomputer shown in Fig. 8;

Fig. 12 shows an example of a function of a weighted mean ratio which changes according to the stability of earth magnetism;

Fig. 13 shows a flow-chart of an operation of a microcomputer for continuously changing the ratio according to a magnetic stability;

Figure 1 shows a fundamental construction of a driving direction sensor according to the present invention. As shown in Fig. 1, this driving sensor includes an earth magnetism sensor 1, a rate gyro sensor 2 and a direction compensating unit 3. The earth magnetism sensor 1 detects an angle of the driving direction relative to a magnetic north of earth magnetism and calculates the driving direction on a map. A flux gate sensor is a typical example of the earth magnetism sensor 1. The rate gyro sensor 2 detects a rotating speed of an object to which the rate gyro sensor 2 is attached, and calculates a rotated angle from the detected rotating speed, and then outputs a driving direction obtained by adding the rotated angle to a reference direction. The direction compensating unit 3 calculates a compensated driving direction by weighted mean process of the outputs from the earth magnetism sensor 1 and the rate gyro sensor 2 and sets the compensated direction as a reference direc-

tion of the rate gyro sensor 2.

The above driving direction sensor is practically realized by using a microcomputer. Figure 2 shows a construction of the driving direction sensor of an embodiment. In this embodiment, a flux gate sensor 1 corresponds to the earth magnetism sensor and an optical fiber gyro 2 corresponds to the rate gyro sensor. Figure 3 shows a detailed construction of the flux gate sensor 1. We abbreviated the detailed explanation of the construction shown in Fig. 3 because it is well known. The flux gate sensor outputs two voltage signals corresponding to X direction component and Y direction component of earth magnetism. The above X and Y directions are directions of the flux gate sensor 1, namely a forward direction of a vehicle and a perpendicular direction to the above direction.

In Fig. 2, the output of the flux gate sensor 1 is converted to digital signals by an analog-to-digital (A-D) converter 32. The microcomputer 31 periodically reads these output signals and calculates a first driving direction on a map from the output of the flux gate sensor 1 by compensating the difference between the map north and the earth magnetism north. Similarly, the optical fiber gyro 2 outputs a signal corresponding to the rotating angular speed and the output signal also converted to a digital signal by a A-D converter 33. The microcomputer 31 periodically reads this signal and calculates a rotated angle from a reference direction. This reference direction is stored in the microcomputer 31. The microcomputer 31 calculates a second driving direction by adding the rotated angle to the reference direction. The microcomputer 31 further calculates a compensated driving direction from the first and second driving directions and sets the compensated driving direction as the reference direction. Namely, in this embodiment, the microcomputer 31 performs the calculating processes of the flux gate sensor 1 and the optical fiber gyro 2 in addition to the calculating process of the compensated driving direction. This detection process of the driving direction is performed at a predetermined period.

A flow-chart as shown in Figs. 4A and 4B shows the calculating operation of the microcomputer 31 for obtaining the compensated driving direction. At the beginning, the initialization of the optical fiber gyro 2 is performed by setting the reference directionto the first driving direction. At step 101, the microcomputer 31 reads outputs (cdx, cdy) of the flux gate sensor 1 and converts these output data to a first driving direction $\overrightarrow{cd}$ at step 102. At step 103, the reference direction $\overrightarrow{as}$ is set to this $\overrightarrow{cd}$.

As described in the above, because detections of the compensated driving direction are performed at the predetermined sampling terms, the microcomputer performs a counting operation for adjusting the sampling timing at step 104. At step 105, the microcomputer 31 reads the outputs (cdx_t, cdy_t) of the flux gate sensor 1 and the output $\overrightarrow{md}_t$ of the optical fiber gyro 2. These output data are respectively converted to the first driving direction $\overrightarrow{cd}_t$ and the rotated angle $\overrightarrow{md}_t$ at step 106. At step 107, the second driving direction $\overrightarrow{ag}_t$ is calculated by adding the rotated angle $\overrightarrow{md}_t$ to the reference angle $\overrightarrow{as}$.

At step 108, the weighted mean ratio W is determined. The determination process of this ratio W will be explained later. If this ratio is constant, this step 108 can be excluded. At step 109, the compensated driving direction $\overrightarrow{d}_t$ is obtained by calculating the weighted mean of the first driving direction $\overrightarrow{cd}_t$ and the second driving direction $\overrightarrow{md}_t$ according to the following equation (1).

$$\overrightarrow{d}_t = (1 - W) \times \overrightarrow{cd}_t + W \times \overrightarrow{ag}_t \qquad (1)$$

The compensated driving direction $\overrightarrow{d}_t$ is set to the reference direction as at step 110. The microcomputer 31 outputs this compensated driving direction to the navigation system at step 111. And then, the control returns to step 104, and repeats steps 104 through 111.

In the following, the error of the compensated driving direction $\overrightarrow{d}_t$ in a short time range and a long time range is explained. As described in the above, an output of the earth magnetism sensor, such as a flux gate sensor 1, has a random error due to external disturbance. Now, suppose that the first driving direction $\overrightarrow{cd}_t$ detected at a specific sampling timing has a direction error $\overrightarrow{a}_t$ and the correct direction at that time is $\overrightarrow{x}_t$.. The first driving direction $\overrightarrow{cd}_t$ is expressed by a following equation (2).

$$\overrightarrow{cd}_t = \overrightarrow{x}_t + \overrightarrow{a}_t \quad (2)$$

The rate gyro sensor, such as an optical fiber sensor 2, detects a rotating speed and calculates a rotated angle from a reference angle. The detection error of the rotating speed changes due to factors such as temperature, however, it is nearly constant. This error is very small in a high precision rate gyro sensor such as the type included in this invention. The rotated angle is obtained by multiplying the rotating speed by the time duration. Therefore, the rotated angle has an error proportional to the error of the rotating speed. Now, it is supposed that the detection error of the rotated angle at a specific sample timing has a constant error $\overrightarrow{g}$ and the correct direction at that time is also $\overrightarrow{x}_t$. . Because the conventional rate gyro sensor detects the rotated angle at a predetermined sampling cycle and calculates the direction by adding the rotated angle to the reference direction, and further sets the calculated direction to the reference direction, the detected direction $\overrightarrow{ag}_t$ at t times is expressed by the following equation (3).

$$\overrightarrow{ag}_t = \overrightarrow{x}_t + (t - 1) \times \overrightarrow{g} \quad (3)$$

As shown in the equation (3), the detection error of the rate gyro sensor accumulates with the sample number. In the following description, the first reference direction is supposed to be set in the correct direction.

The first driving direction $\overrightarrow{cd}_1$ and the second driving direction detected $\overrightarrow{ag}_1$ at the first sampling time are respectively expressed by following equations (4) and (5).

$$\overrightarrow{cd}_1 = \overrightarrow{x}_1 + \overrightarrow{a}_1 \quad (4)$$

$$\overrightarrow{ag}_1 = \overrightarrow{x}_1 + \overrightarrow{g} \quad (5)$$

The compensated driving direction d_1 obtained by weighted mean with a ratio W expressed by the following equation (6).

$$\begin{aligned}\overrightarrow{d}_1 &= (1 - W) \times (\overrightarrow{x}_1 + \overrightarrow{a}_1) + W \times (\overrightarrow{x}_1 + \overrightarrow{g}) \\ &= \overrightarrow{x}_1 + (1 - W) \times \overrightarrow{a}_1 + W \times \overrightarrow{g} \quad (6)\end{aligned}$$

Consequently, the compensated driving direction obtained at the first sampling has an error $\overrightarrow{e}_1$ expressed by the following equation (7).

$$\overrightarrow{e}_1 = (1 - W) \times \overrightarrow{a}_1 + W \times \overrightarrow{g} \quad (7)$$

When the ratio W is 0.9, the influence of the external magnetic disturbance is reduced to 1/10. And at that time, the error $\overrightarrow{g}$ of the rate gyro becomes only 9/10. However, because the error $\overrightarrow{g}$ is very small, the error $\overrightarrow{g}$ does not influence the compensated driving direction. If the ratio W is nearer to 1, the influence of the magnetic disturbance is smaller. In practice, the ratio W is 1/100 through 1/5000 for 0.5 second sampling term. Therefore, although the detection error a_1 due to the intensity of the magnetic disturbance is large, the error of the compensated driving direction is not large.

After setting the above compensated driving direction $\overrightarrow{d}_1$ as the reference direction, the second sampling is performed after the predetermined term. The driving directions obtained at the second sampling process are expressed by the following equations (8) and (9).

$$\overrightarrow{cd}_2 = \overrightarrow{x}_2 + \overrightarrow{a}_2 \quad (8)$$

$$\overrightarrow{ag}_2 = \overrightarrow{x}_2 + (1 - W) \times \overrightarrow{a}_2 + W \times \overrightarrow{g} + \overrightarrow{g} \quad (9)$$

The second compensated driving direction $\vec{d}_2$ obtained from above $\overline{cd}_2$ and $\overrightarrow{ag}_2$ is expressed by the following equation (10).

$$\vec{d}_2 = \vec{x}_2 + W\times(W + 1)\times 9 + (1 - W)\times(W\times\vec{a}_1 + \vec{a}_2) \qquad (10)$$

After repeating these process for k times, the obtained compensated driving direction $\vec{d}_k$ is expressed by the following equation (11).

$$\begin{aligned}\vec{d}_k &= \vec{x}_k + W\times(W^{k-1} + W^{k-2} + \ldots + 1)\times\vec{g} \\ &\quad + (1 - W)\times(W^{k-1}\times\vec{a}_1 + W^{k-2}\times\vec{a}_2 + \ldots \div \vec{a}_k) \\ &= \vec{X}_k + W\times(W^k - 1)/(W - 1)\times\vec{g} \\ &\quad + (1 - W)(W^{k-1}\times\vec{a}_1 + \ldots + \vec{a}_k) \qquad (11)\end{aligned}$$

Because W is less than 1, the second term of the equation (11) becomes negligible when the sampling times k becomes very large. Consequently, the equation (11) is the following equation (12).

$$\begin{aligned}dk_k &= \vec{x}_k + W/(1 - W)\times\vec{g} + (1 - W)(W^{k-1}\vec{a}_1 \\ &\quad + \ldots + \vec{a}_k) \qquad (12)\end{aligned}$$

Further, the errors of the earth magnetism sensor due to the external magnetic disturbance is disposed to be zero by averaging sampling values for a long time, therefore, the third term of the equation (12) is negligible. Then, the equation (12) is the following equation (13).

$$\vec{d}_k = \vec{x}_k + W/(1 - W)\times\vec{g} \qquad (13)$$

When the ratio W is 0.9, the equation (13) shows that the error of the compensated driving direction is 9 * $\vec{g}$. As described already, the error $\vec{g}$ is very small, therefore, this error is not the problem. If the ratio W becomes nearer to 1, the error of the compensated driving direction $\vec{d}_k$ becomes larger and is not negligible. Therefore, the ratio W needs to be determined by considering the error of the rate gyro.

As described in the above, the driving direction sensor according to the present invention maintains accuracy in a long time range and also is accurate in a short time range because the compensation process by the first driving direction of the earth magnetism sensor having sudden errors is not performed.

In the above embodiment, the weighted mean ratio W is constant. However, the detection accuracy of the direction sensor can be improved by changing the ratio W according to specific functions. Figure 5 shows an example of the function in which the ratio W changes according to the operation time of the direction sensor from the start initialization. As described in the above, since the rate gyro sensor has a high detection accuracy in a short time range, the rate gyro sensor influences more the compensated direction by setting the ratio W near to 1 and the influence of the error of the earth magnetism sensor can be reduced. Then, when the errors of the rate gyro sensor accumulate after a long operation time, the averaged errors of the earth magnetism sensor, namely, the absolute direction greatly influences the compensated direction by decreasing the ratio W.

The detection error of the rate gyro sensor generally changes according to the temperature of the sensor. Figure 6 shows another example of the function in which the ratio W changes according to the temperature of the rate gyro sensor or the environmental temperature. In order to realize this embodiment, the construction of the direction sensor as shown in Fig. 2 includes a temperature sensor. As the detection error of the rate gyro sensor generally increases according to the increase in temperature, the ratio W is nearer to 1 and the rate gyro sensor contributes to the compensated direction when the temperature is low.

Next, an embodiment of a navigation system having the above direction sensor is described. As described in the above, the earth magnetism is disturbed by various external magnetic factors. In these external magnetic factors, the disturbance of specific facilities and topographical factors cannot be compensated for because these influences occur at random. Consequently, the detected direction of the earth magnetism sensor has a large error at the positions in which the level of magnetic disturbance is large. Since the above direction sensor obtains the compensated direction by weighted mean process of outputs of the earth magnetism sensor and the rate gyro sensor, the error of the earth magnetism sensor due to external disturbance is reduced in the compensated direction. However, the accuracy of the compensated direction can be further improved by excluding the inaccurate output of the earth magnetism sensor from the calculation. Therefore, this navigation system has distribution information of magnetic disturbance to earth magnetism in a form corresponding to the road map and changes the ratio W according to the magnetic disturbance intensity at the locating position. This distribution information of magnetic disturbance is previously detected and stored in a storing unit.

Figure 7 shows a fundamental construction of a navigation system according to the invention. Similar to a conventional navigation system, this navigation system includes a driving direction sensor 10, a driving distance sensor 4, a road map storing unit 5, a locating position calculating unit 6, and a display 9. The driving direction sensor 10 is the above-mentioned direction sensor. This navigation system further includes a disturbance data storing unit 7 and a ratio changing unit 8. The disturbance data storing unit 7 stores information for showing magnetic disturbance intensities on the road map. The ratio changing unit 8 receives a locating position from the locating position calculating unit 6, and detects the magnetic disturbance intensity at the locating position from the disturbance data storing unit 7, and calculates the ratio W corresponding to the magnetic disturbance intensity, and then outputs the ratio W to the direction compensating unit 3.

Practically, a CD-ROM player is used as the road map storing unit 5 and the disturbance data storing unit 7, and the locating position calculating unit 6 and the ratio changing unit 8 are realized by a microcomputer. Figure 8 shows a construction of this navigation system. In Fig. 8, a flux gate sensor 1, an optical fiber gyro 2, and A-D converters 32, 33 are the same as those shown in Fig. 2. A wheel speed sensor 4 detects a rotating angle of wheels and outputs a signal having a number of pulses corresponding to the rotating angle. These pulses are counted at a counter 34. A microcomputer 31 detects the value of the counter 31 and calculates the driving distance. Further, the microcomputer calculates a locating position from the driving direction and the driving distance. C-D ROMs set in a C-D ROM player 71 include information of road map data and magnetic disturbance data. The microcomputer 31 reads the information of road map data and, practically, compensates the locating position by a map matching method. The microcomputer 31 sends data of the locating position and map data, and the locating position and the map are displayed on a CRT 9. The microcomputer 31 reads the data of the magnetic disturbance at the locating position and determines the ratio W of the weighted mean process.

In this embodiment, the magnetic disturbance data includes locating positions of specific facilities and respective disturbance ranges of the specific facilities in which each disturbance of the specific facility to earth magnetism is more than a predetermined level. Figure 9 shows an example of this magnetic disturbance data. This data includes a transmitting station, a bridge and a railroad line as specific facilities. The disturbance range of the transmitting station is a circle of a radius R_1. Therefore, the data relating to the transmitting station can be expressed by co-ordinate values of the locating position and the radius R_1. The disturbance range of the bridge can be expressed as shown in Fig. 9. The data relating to the bridge can be expressed by co-ordinate values of center positions of two semicircles and the radius R_2. The disturbance range of the railroad line spreads along the line. However, the practical influence ranges are limited to crossing areas. Therefore, in this embodiment, the disturbance range of the railroad line is expressed by locating positions of crossings and the radius of circles centering at the crossings.

The disturbance ranges of the specific facilities shown in Fig. 9 are comparatively small. However, several types of specific facilities have large disturbance ranges. A high level road, a transmission line are included to these types. Further, a railroad line also has a large disturbance range when the railroad extends parallel to roads. When specific facilities have large or long disturbance ranges, the disturbance ranges cannot be expressed by a pair of co-ordinate values and a radius. In these cases, disturbance ranges can be expressed by a chain of positions and widths. This width corresponds to the radius.

Figure 10 shows an example of formats of the magnetic disturbance data. The large disturbance range is expressed by several points.

The compensated driving direction of a vehicle is calculated with the normal ratio W_0 when the vehicle drives in a normal area except the disturbance range and the ratio W changes to W_x. W_x is smaller than W_0. Namely, the contribution ratio of the earth magnetism sensor is reduced in the disturbance range.

Figures 11A and 11B show a flow-chart of the microcomputer operation for changing the weighted mean ratio W according to a locating position. An initialization is performed at step 200. A reference direction setting

process and a starting position setting process are included in this initialization. At step 201, the ratio W is set to W_0 for the normal range. At step 202, the microcomputer 31 detects the output of the flux gate sensor 1 and the optical fiber gyro 2 and calculates the compensated driving direction by the ratio W_0. At step 203, the microcomputer 31 detects the output of the wheel speed sensor 4 and calculates the driving distance. At step 204, the microcomputer 31 calculates the locating position from the driving direction and the driving distance.

At step 205, it is determined whether or not the road map data in the microcomputer 31 is appropriate to the locating position, because the necessary road map data changes according to the locating position. If the change of the road map data is necessary, the microcomputer 31 reads the road map data and the magnetic disturbance data corresponding to the locating position at step 206. If it is not necessary, the control jumps to step 207.

At step 207, it is determined whether or not there are specific facilities in the neighborhood of the locating position. If there are no specific facilities, the control returns to step 202. If there are, the distances from the locating position to the specifications are calculated at step 208. Then, it is determined whether or not the locating position is within the disturbance range of the specific facilities. If the locating position is out of the disturbance range, the control returns to step 202. If the locating position is within the disturbance range, the control proceeds to step 210.

At step 210, the ratio W is set to W_x. The operations from step 211 through 215 are the same as those of step 202 through 206 except the ratio W is different. Further, the operations from step 216 to 217 are the same as those of step 208 to 209. If the locating position is still within the disturbance range, the control returns to step 211. If the locating position is out of the disturbance range, the control returns to step 201.

If W_x is 0, the compensated driving direction is determined only by the output of the rate gyro sensor within the disturbance range.

Further, if W_0 is 1, the compensated driving direction is determined only by the output of the earth magnetism sensor out of the disturbance range.

In the above embodiment, the ratio W changes between W_0 and W_x whether the locating position is within the disturbance range or not. Namely, the ratio W changes like a step function. However, in practice, the specific facility continuously disturbs the magnetic field. Therefore, if the ratio W changes according to the intensity of the disturbance, the compensated driving direction can improve. An embodiment in which the ratio W continuously changes according to the intensity of the disturbance is described in the following.

Generally, the disturbance intensity changes according to the square of the distance from the specific facility. Therefore, when the magnetic disturbance data includes positions of the specific facility and intensities at centers, the disturbance intensity can be obtained by calculating the distance from the locating position to the specific facility. Figure 12 shows an example of a function of the ratio W changing according to the earth magnetism stability. The earth magnetism stability corresponds to the disturbance intensity.

Figure 13 shows a flow-chart of the operation of the microcomputer in this embodiment. Since each of the operations is almost the same as that of Fig. 11, only different steps are explained. At step 304, distances to specific facilities in the neighborhood of the locating position are calculated. At step 305, each disturbance intensity of the specific facility in the neighborhood is calculated, and a total disturbing intensity is calculated by adding all disturbance intensities. And then, the ratio W is determined according to the function shown in Fig. 12.

In the above embodiments, the magnetic disturbance data is expressed by specific facilities. The magnetic disturbance data can be expressed by another format. For example, all positions on the map are divided into several zones each of which respectively has the disturbance intensity of the same degree. And, the ratio W is determined according to the zone which the locating position belongs to. This magnetic disturbance data includes disturbances due to topological factors.

Further, in the above navigation system, the compensated driving direction is calculated by the weighted mean method. However, this method for changing the calculated process of the compensated driving direction according to the magnetic disturbance intensity at the locating position can be applied to other methods for calculating the compensated driving direction.

Claims

1. A driving direction sensor of a vehicle for outputting a compensated direction, comprising:

   an earth magnetism sensor (1) for detecting a forward angle relative to magnetic north of earth and outputting a first driving direction calculated from said detected forward angle,

   a rate gyro sensor (2) for calculating a rotated angle from detected rotating speed and for outputting a second driving direction obtained by adding said rotated angle to a reference direction, and

a direction compensating means (3) for calculating a compensated direction from said first driving direction and said second driving direction,

characterized in that said direction compensating means (3) calculates said compensated direction by a weighted mean process of said first driving direction and said second driving direction, and sets said compensated direction as said reference direction of said rate gyro sensor.

2. A driving direction sensor of a vehicle as set forth in claim 1, wherein a weighted mean ratio of said weighted mean process changes according to a driving time of said vehicle.

3. A driving direction sensor of a vehicle as set forth in claim 1, wherein a weighted mean ratio of said weighted mean process changes according to a temperature of said rate gyro sensor (2) or an environment temperature of said rate gyro sensor (2).

4. A navigation system comprising:

a driving direction sensor (10) for detecting a driving direction,

a driving distance sensor (4) for detecting a driving distance,

a road map storing means (5) for storing information relating to a road map, and

a locating position calculating means (6) for calculating a locating position on said road map,

characterized in that said driving direction sensor (10) is a direction sensor as set forth in claim 1.

5. A navigation system as set forth in claim 4, wherein said navigation system comprising:

a disturbance data storing means (7) for storing distribution information of magnetic disturbance to earth magnetism in a form corresponding to said road map, and

a ratio changing means (8) for detecting an intensity of magnetic disturbance at said locating position from said disturbance data storing means (7) and changing a weighted mean ratio of said weighted mean process according to said magnetic disturbance intensity.

6. A navigation system as set forth in claim 5, wherein said disturbance data storing means (7) comprises locating positions of specific facilities and respective influence ranges of said specific facilities in which each disturbance of said specific facilities to earth magnetism is more than a predetermined level,and

said ratio changing means (8) further comprises a distance calculating means for calculating distances between said specific facilities and said locating position and changes said weighted mean ratio whether or not said locating position is within said influence range.

7. A navigation system as set forth in claim 6, wherein said ratio changing means (8) changes said weighted mean ratio of said first driving direction to 0 when said locating position is within said disturbance range.

8. A navigation system as set forth in claim 6, wherein said ratio changing means (8) changes said weighted mean ratio between 0 and 1.

9. A navigation system of a vehicle for offering a locating position on a map, comprising:

an earth magnetism sensor (1) for detecting a forward angle relative to magnetic north of earth and outputting a first driving direction calculated from said detected forward angle,

a rate gyro sensor (2) for calculating a rotated angle from detected rotating speed and for outputting a second driving direction obtained by adding said rotated angle to a reference direction,

a direction compensating means (3) for calculating a compensated direction from said first driving direction and said second driving direction,

a driving distance sensor (4) for detecting a driving distance,

a road map storing means (5) for storing information relating to a road map, and

a locating position calculating means (6) for calculating a locating position on said road map,

characterized in that said navigation system comprising:

a disturbance data storing means (7) for storing distribution information of magnetic disturbance to earth magnetism in a form corresponding to said road map, and

a changing means (8) for detecting an intensity of magnetic disturbance at said locating position and changing a calculating process of said compensated direction.

Fig. 1

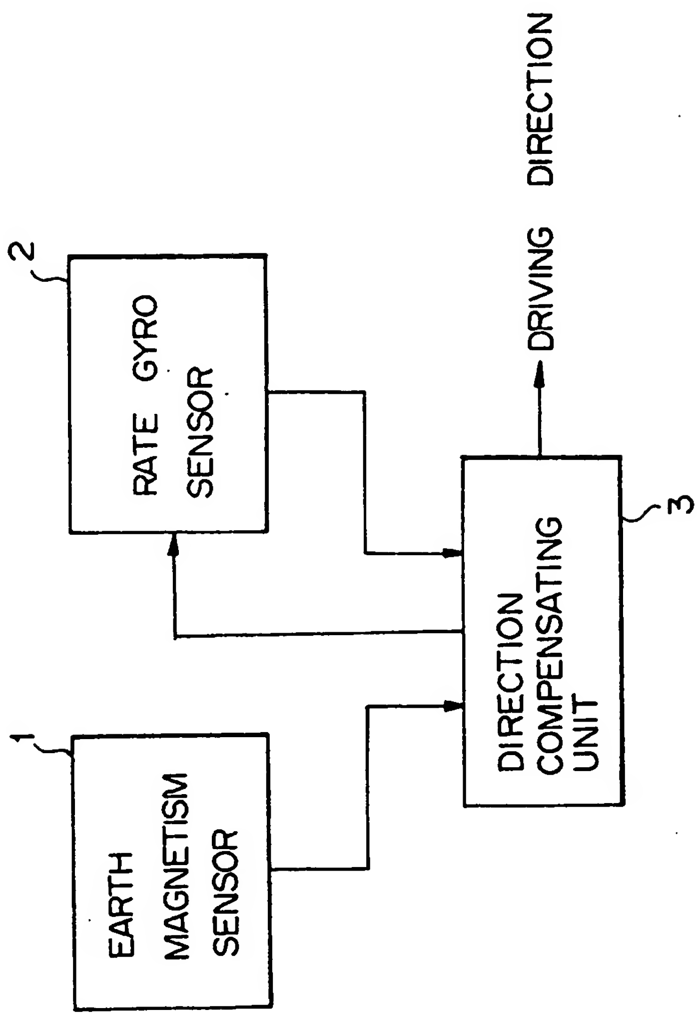

EARTH
MAGNETISM
SENSOR
1
RATE GYRO
SENSOR
2
DIRECTION
COMPENSATING
UNIT
3
DRIVING DIRECTION

Fig. 2

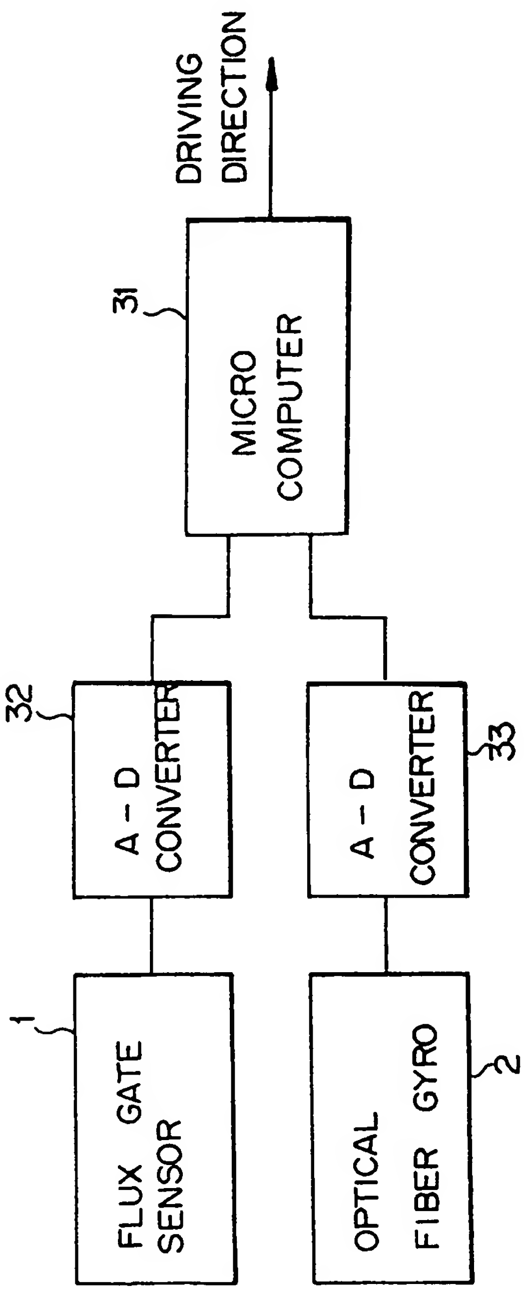

FLUX GATE SENSOR
1
A - D CONVERTER
32
OPTICAL FIBER GYRO
2
A - D CONVERTER
33
MICRO COMPUTER
31
DRIVING DIRECTION

Fig. 3

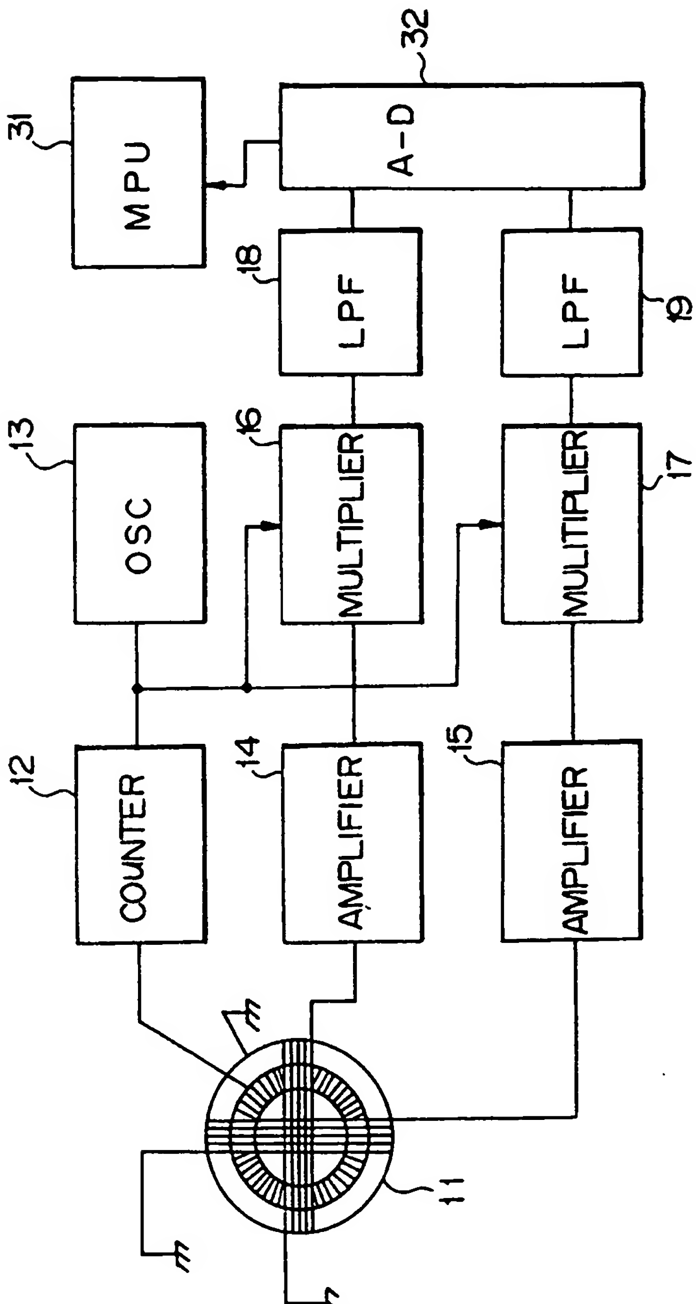

MPU
31
A-D
32
OSC
13
LPF
18
LPF
19
MULTIPLIER
16
MULITIPLIER
17
COUNTER
12
AMPLIFIER
14
AMPLIFIER
15
11

Fig. 4

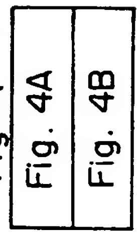


Fig. 4A
Fig. 4B

Fig. 4A

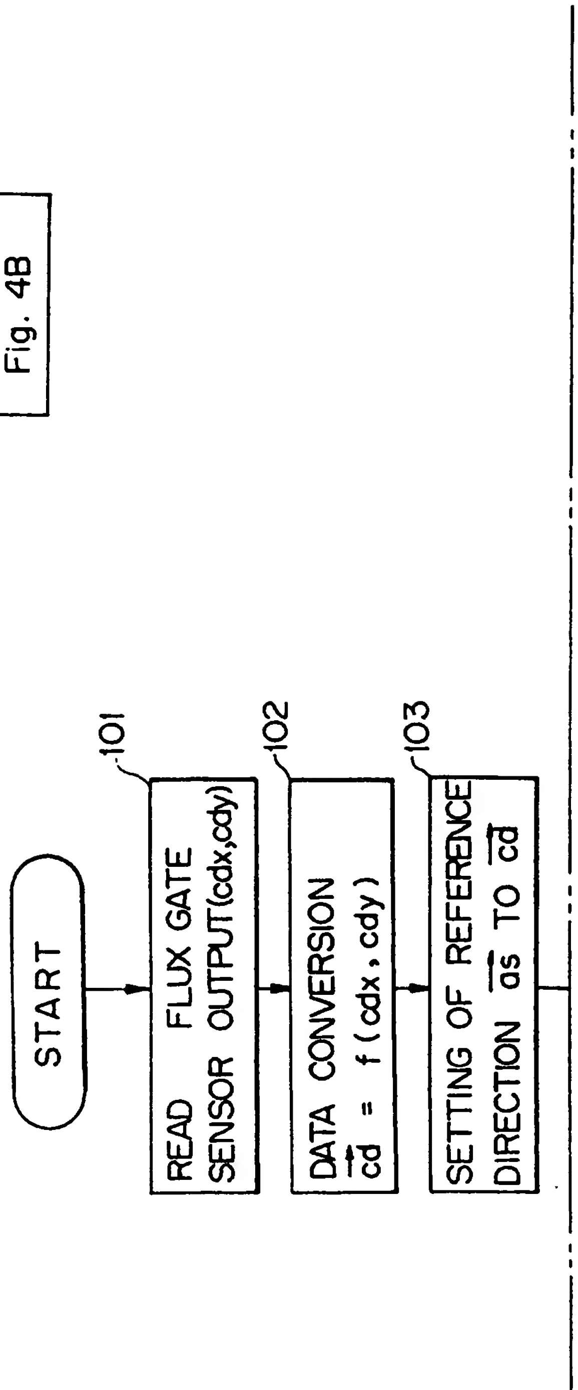

START
101
READ FLUX GATE SENSOR OUTPUT(cdx,cdy)
102
DATA CONVERSION
cd = f(cdx, cdy)
103
SETTING OF REFERENCE DIRECTION as TO cd

Fig. 4B

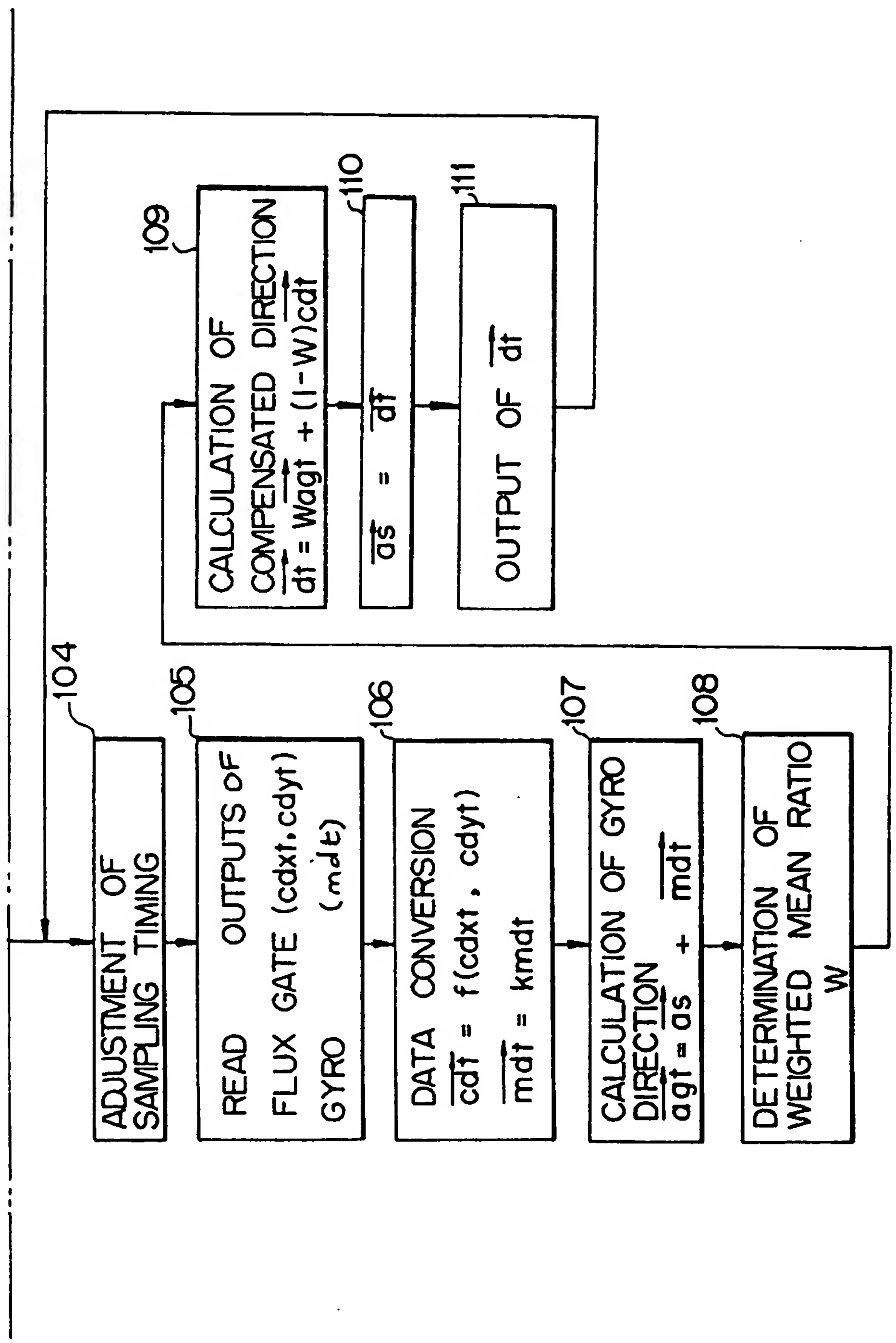

104
ADJUSTMENT OF SAMPLING TIMING
105
READ OUTPUTS OF
FLUX GATE (cdxt, cdyt)
GYRO (mdt)
106
DATA CONVERSION
$\overrightarrow{cdt}$ = f(cdxt, cdyt)
$\overrightarrow{mdt}$ = kmdt
107
CALCULATION OF GYRO DIRECTION
$\overrightarrow{agt}$ = $\overrightarrow{as}$ + $\overrightarrow{mdt}$
108
DETERMINATION OF WEIGHTED MEAN RATIO W
109
CALCULATION OF COMPENSATED DIRECTION
$\overrightarrow{dt}$ = W$\overrightarrow{agt}$ + (1-W)$\overrightarrow{cdt}$
110
$\overrightarrow{as}$ = $\overrightarrow{dt}$
111
OUTPUT OF $\overrightarrow{dt}$

Fig. 5

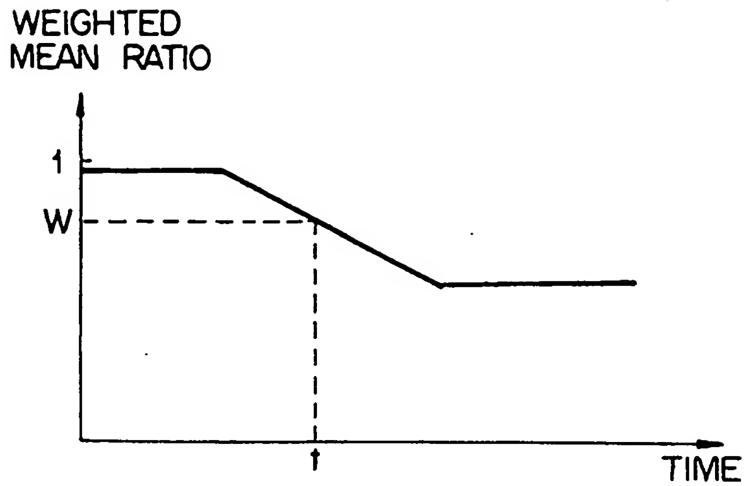


Fig. 6

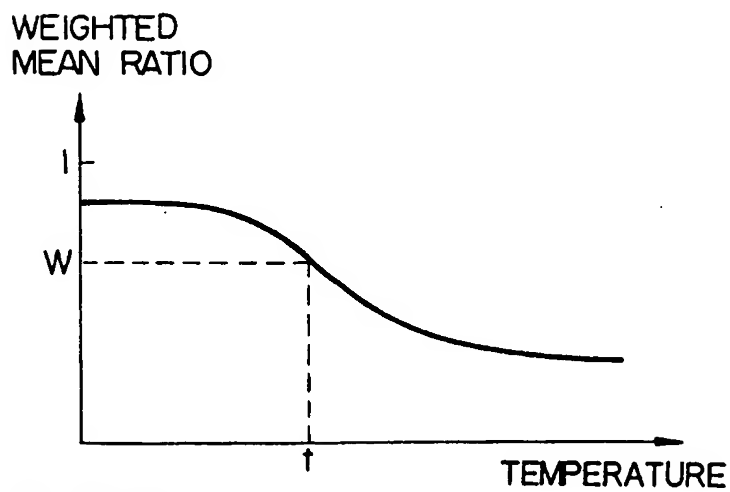


Fig. 12

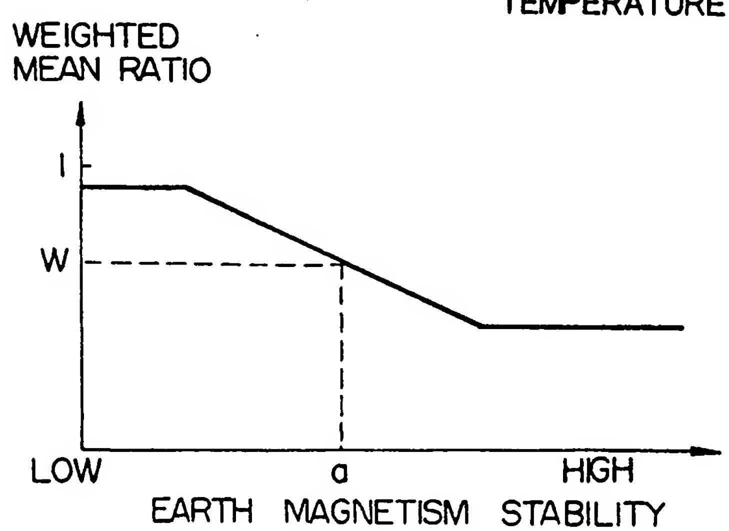


Fig. 7

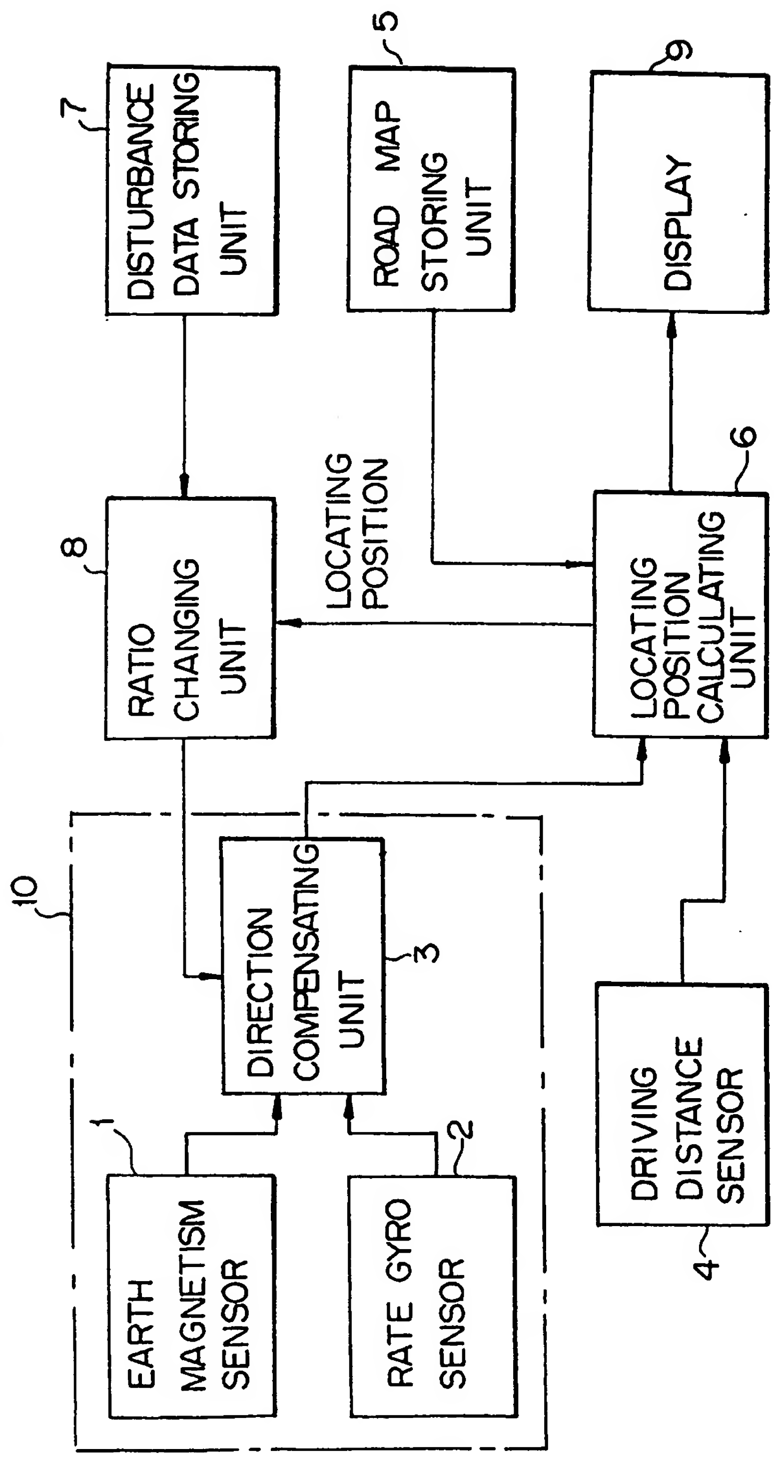

DISTURBANCE DATA STORING UNIT
7
ROAD MAP STORING UNIT
5
DISPLAY
9
RATIO CHANGING UNIT
8
LOCATING POSITION
LOCATING POSITION CALCULATING UNIT
6
10
DIRECTION COMPENSATING UNIT
3
EARTH MAGNETISM SENSOR
1
RATE GYRO SENSOR
2
DRIVING DISTANCE SENSOR
4

Fig. 8

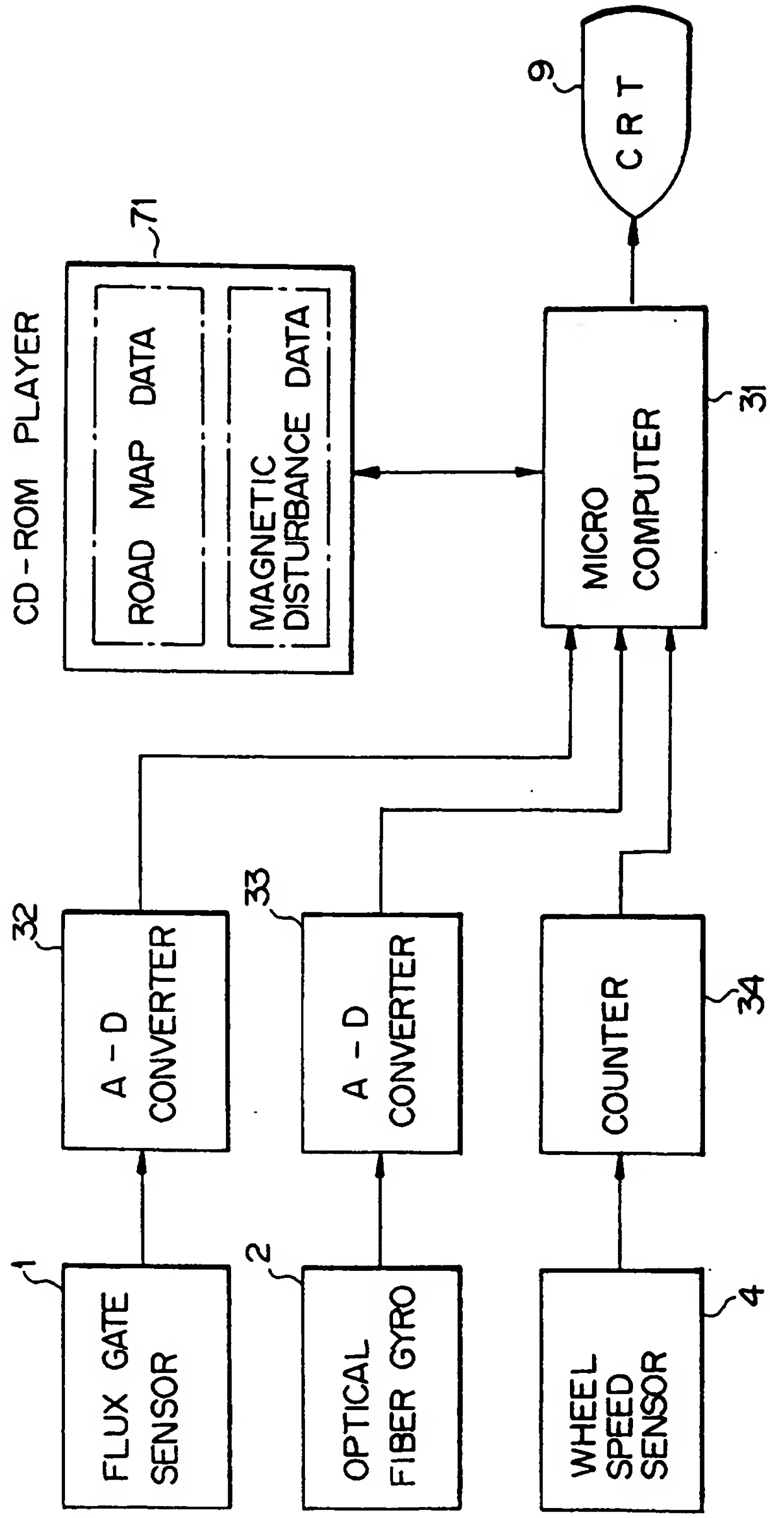

CD-ROM PLAYER
ROAD MAP DATA
MAGNETIC DISTURBANCE DATA
71
CRT
9
MICRO COMPUTER
31
FLUX GATE SENSOR
1
A - D CONVERTER
32
OPTICAL FIBER GYRO
2
A - D CONVERTER
33
WHEEL SPEED SENSOR
4
COUNTER
34

Fig. 9

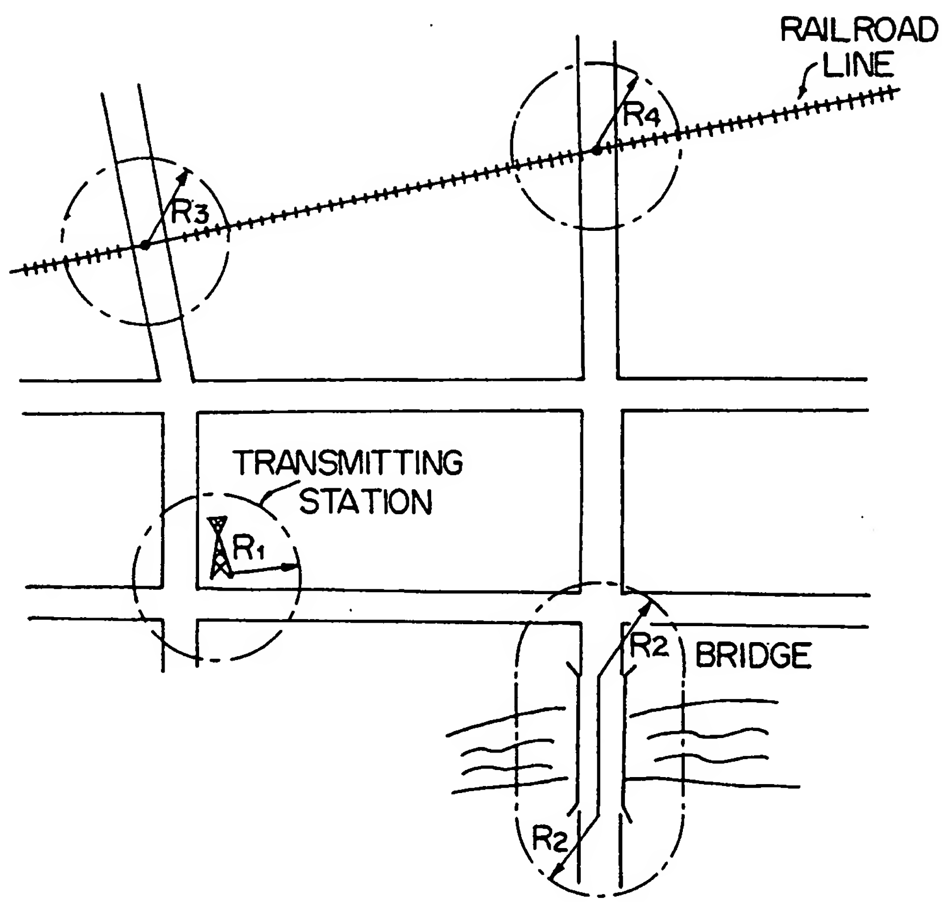


Fig. 10

CLASS	NAME	NUMBER OF POINTS	POINT 1	RADIUS 1	POINT 2	RADIUS 2	. . .
TOWER	TRANSMISSION STATION	1	X_1 , Y_1	R_1	—	—	—
BRIDGE	IRON	2	X_{21} , Y_{21}	R_{21}	X_{22} Y_{22}	R_{22}	—
RAILROAD	CROSSING	1	X_3 , Y_3	R_3	—	—	—
RAILROAD	CROSSING	1	X_4 , Y_4	R_4	—	—	—
BUILDING	BUILDING	1	X_5 , Y_5	R_5			
ROAD	HIGL LEVEL	30	X_{61} , Y_{61}	R_{61}	X_{62} Y_{62}	R_{62}	X_{63} Y_{63}
⋮	⋮	⋮	⋮	⋮	⋮	⋮	

Fig. 11A

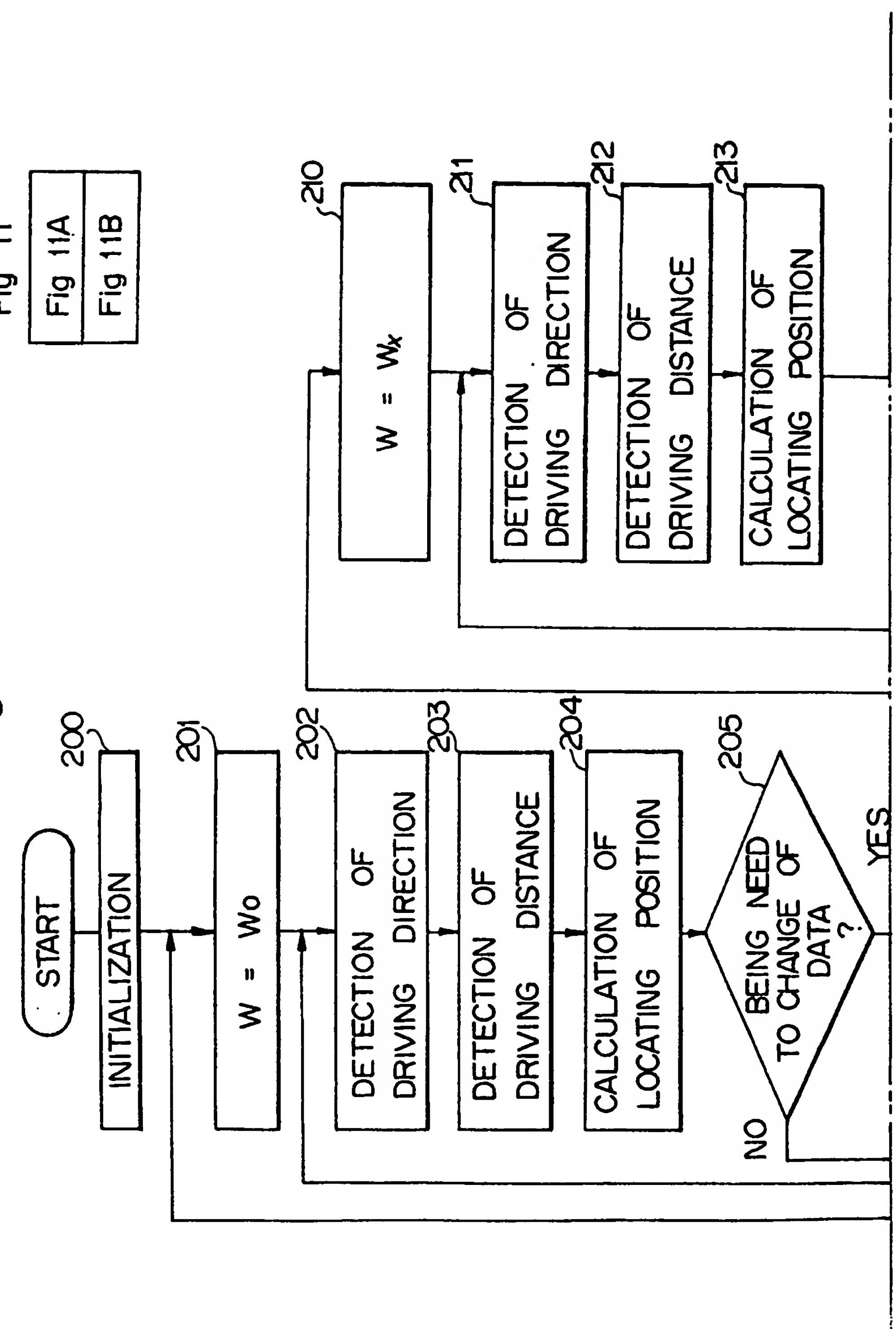


Fig 11
Fig 11A
Fig 11B
START
200
INITIALIZATION
201
W = Wo
202
DETECTION OF DRIVING DIRECTION
203
DETECTION OF DRIVING DISTANCE
204
CALCULATION OF LOCATING POSITION
205
BEING NEED TO CHANGE OF DATA ?
YES
NO
210
W = Wx
211
DETECTION OF DRIVING DIRECTION
212
DETECTION OF DRIVING DISTANCE
213
CALCULATION OF LOCATING POSITION

Fig. 11B

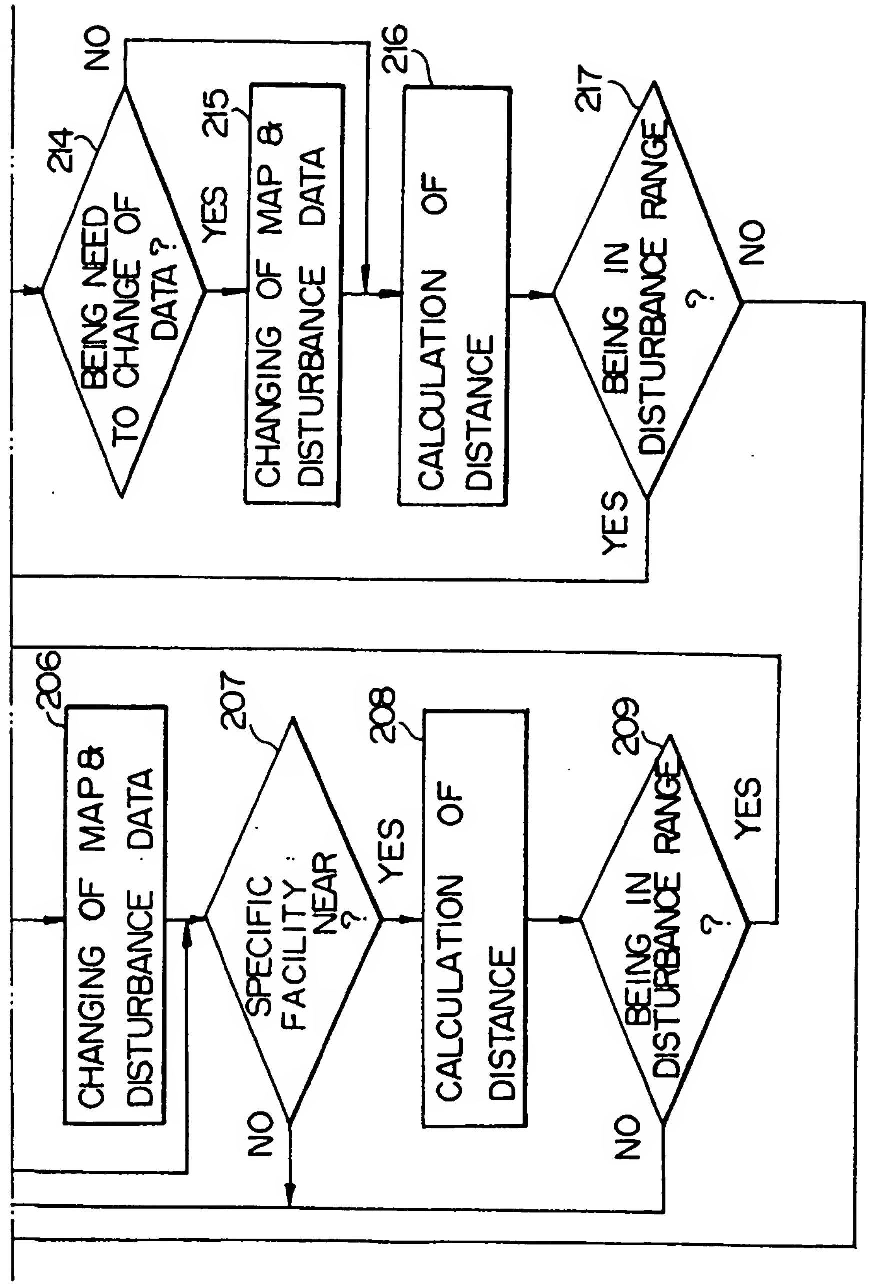
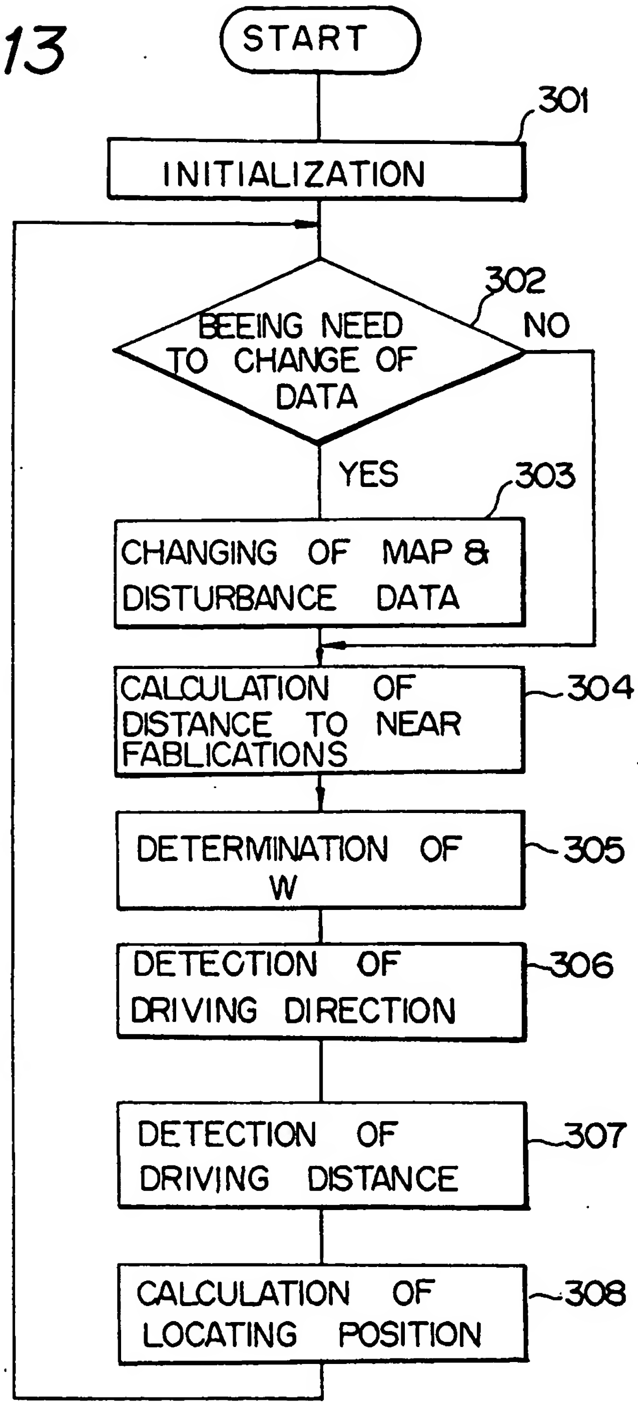

206
CHANGING OF MAP & DISTURBANCE DATA
207
SPECIFIC FACILITY NEAR ?
YES
NO
208
CALCULATION OF DISTANCE
209
BEING IN DISTURBANCE RANGE ?
YES
NO
214
BEING NEED TO CHANGE OF DATA ?
YES
NO
215
CHANGING OF MAP & DISTURBANCE DATA
216
CALCULATION OF DISTANCE
217
BEING IN DISTURBANCE RANGE ?
YES
NO

Fig. 13


START
301
INITIALIZATION
302
BEEING NEED TO CHANGE OF DATA
NO
YES
303
CHANGING OF MAP & DISTURBANCE DATA
CALCULATION OF DISTANCE TO NEAR FABLICATIONS
304
DETERMINATION OF W
305
DETECTION OF DRIVING DIRECTION
306
DETECTION OF DRIVING DISTANCE
307
CALCULATION OF LOCATING POSITION
308